USE OF PRECISION FARMING TO IMPROVE APPLICATIONS OF FEEDLOT WASTE TO INCREASE NUTRIENT USE EFFICIENCY AND PROTECT WATER QUALITY

T. J. Masek,[1] J. S. Schepers,[2,*] S. C. Mason,[1] and D. D. Francis[2]

[1] T.J. Masek and S.C. Mason, Dep. of Agronomy,
Univ. of Nebr., Lincoln, NE 68583-0915
[2] J.S. Schepers and D. D. Francis, USDA-Agric. Research Service
and Dep. of Agronomy, Univ. of Nebr., Lincoln, NE 68583-0915

ABSTRACT

Spatial variability in crop yields can be caused by many factors, which makes it difficult to determine the most limiting factors. Application of animal wastes to relatively infertile areas offers the potential to supply needed nutrients and improve soil physical properties. The objectives of this study were to test a manure application strategy to reduce spatial variability in corn (Zea mays L) yield and to identify the most limiting nutrients in relatively low yielding areas in a field. Fresh solid beef feedlot manure was applied in 1997 to a strip across areas with variable fertility status. No fertilizer was applied with the manure in 1997. Uniform N fertilizer, but no manure, was applied in 1998. Leaf tissue samples and chlorophyll meter readings were collected along the strips during the growing season and from adjacent strips without manure

* Corresponding author. E-mail: jschepers1@unl.edu

application. Grain yield was determined at plant maturity. In 1997, chlorophyll meter readings indicated season long N deficiency (<95% sufficiency index) in no-manure plots with sufficiency indices of 93, 88, 85, and 88% for the V10, V17, R2, and R3 growth stages, respectively. Only an early season N deficiency was detected in a few of the no-manure plots in 1998. Leaf tissue analyses indicated N and P were growth limiting factors in 1997, with leaf N concentrations of 25, 26, and 27 mg g^{-1} for non-manure plots and 30, 33, and 31 mg g^{-1} for manure plots at V12, R1, and R3 growth stages, respectively. Leaf P concentrations were 2.0, 2.0, and 1.9 mg g^{-1} for no-manure plots versus 2.5, 2.7, and 2.3 mg g^{-1} for manure plots, respectively. In 1998, neither N or P were identified as limiting factors. Grain yields in 1997 were 10.2 and 12.2 Mg ha^{-1}, which increased to 11.9 and 12.8 Mg ha^{-1} in 1998 for no-manure and manure plots, respectively.

INTRODUCTION

Spatial variability in crop yield is a perpetual problem that is frequently attributed to soil properties and nutrient availability. Uniform fertilizer application to spatially variable soils usually results in over- and under-fertilized areas. With the advent of yield monitors and global positioning systems (GPS), spatial variability can now be recorded and displayed as a colorful yield map. These yield maps can then be analyzed and displayed using geographic information systems (GIS) so that producers and consultants can identify problem areas within the field. Once areas have been verified to have a likely soil fertility problem, GPS units can be used to define the boundary of relatively infertile areas so that organic amendments such as manure can be applied to minimize the effect of the observed spatial variability.

Application of manure or other organic amendments has been demonstrated to supply nutrients, increase organic matter content, and improve physical properties. Feedlot cattle manure is a valuable resource as a fertilizer and soil amendment (Sommerfeldt and Chang, 1985). In addition to its nutrient supplying capabilities, manure can also improve such soil physical properties as porosity, structure, water infiltration rate, and available water holding capacity (Sweeten and Mathers, 1985). Manure has also been found to reduce surface crusting, soil compaction, and soil bulk density (Tiarks et al., 1974). Sommerfeldt and Chang (1985) demonstrated that manure application to irrigated land tended to decrease the amount of soil aggregates <1 mm while increasing the amount of aggregates >1 mm in size at the 15–30 cm depth. Because of its ability to supply plant nutrients and improve soil physical properties, manure has been used effectively in restoring

productivity to marginal, less fertile, and eroded soils (Hornick, 1982; Larney and Janzen, 1997). However, improvements in soil physical structure may not be evident after one or two growing seasons. The extent to which manure provides nutrients and changes soil physical properties is dependent upon: a) composition of rations fed to livestock, b) method of manure collection and storage, c) ration, bedding, soil, and/or water added, and d) method and time of application to land.

Even though manure is known to provide several benefits to soil and increase productivity, there is a concern for surface and groundwater pollution. High rates and/or perpetual applications of manure can lead to increased nitrate leaching to groundwater and P loss in surface runoff (Sharpley and Smith, 1995). The over-application of manure to relatively high productive areas can lead to greater surface and groundwater pollution than on relatively low productive areas (Sommerfeldt et al., 1988). This emphasizes the importance of imposing good manure management on existing practices that minimize erosion and runoff. The current problem with manure utilization lies in determining maximum safe rates for the environment while meeting crop needs. There needs to be a balance between peak crop nutrient requirements and potential movement through the soil profile when the crop has low or no nutrient requirements.

To facilitate good manure management and minimize pollution potential, chlorophyll meters and tissue sampling can be utilized to monitor crop nutrient status and provide indication of deficiencies in soil. Wood et al. (1992) demonstrated that chlorophyll concentration in corn is positively correlated with leaf N concentration. Schepers et al. (1998) used this relationship to show that chlorophyll meters could be used to monitor the N status of corn and schedule fertilizer applications. Although chlorophyll meters do not measure leaf N concentration, they do provide an indication of potential photosynthesis, which is highly correlated with crop N status.

Tissue testing for plant or grain nutrient concentrations can provide an indication of possible nutrient deficiencies in soil by comparing values with published critical nutrient concentrations (CNC) or critical nutrient ranges. A plant concentration that falls below the CNC may result in a yield reduction. Plant concentrations above the CNC are considered adequate with no yield reduction expected unless values are so high that the element becomes toxic. Some caution is appropriate because plant nutrient concentrations are affected by age and type of tissue, cultivar, nutrient interactions, and the environment (Bates, 1971). A more effective use of tissue sampling is to compare concentrations between leaf tissue from distinctly healthy and stressed areas. In doing so, one can obtain better indications of nutrient deficiencies (if any) that may be present in the stressed areas.

Fertilizers are typically applied uniformly as most fields are fertilized as a single unit. However, there are many occasions when more than one soil type exists in a field, which leads to different crop yield potentials. Plant nutrient status within a field is likely to vary accordingly. Considering such variability, Carr et al.

(1991) suggested the possibility of a "farming soils, not fields" strategy as a potential alternative to conventional fertilizer strategies as a way to improve fertilizer profitability.

By implementing site-specific manure applications, producers can apply manure to relatively infertile areas of the field to supply needed nutrients, improve soil physical properties, and increase crop productivity. Site-specific manure application may also be important in that the manure will be applied to areas where it will be best utilized, thus reducing the potential for surface and groundwater pollution. The objectives of this study were to test a manure application strategy to reduce spatial variability in crop yield of a field and to identify the most limiting nutrients in relatively low yielding areas within a field.

MATERIALS AND METHODS

This experiment was conducted in 1997 and 1998 on a 60-ha center-pivot irrigated field of continuous corn (Zea mays L) located in Buffalo County near Shelton, Nebraska. A ridge-till system, consisting of stalk shredding, strip-rototilling the ridge tops ahead of the planter, and two cultivations during the growing season for weed control and ridge building was used. The soil types within this field included approximately 40% Blendon loam, 0–1% slope (coarse loamy, mixed, mesic Pachic Haplustoll), 20% Blendon loam, 1–3% slope (coarse loamy, mixed mesic Pachic Haplustoll), and 40% Hord silt loam, 0–1% slope (fine-silty, mixed, mesic Cumulic Haplustoll).

This study was super imposed on a terminated project (1994–1996) that had six 32-row wide N treatments with five replications. The strips selected had all received uniform applications of N fertilizer at a conservative rate for the previous three years. Yield monitor data for 1996 were graphed for each replication to identify the low yielding areas. Thirty-two row wide transects were established across these areas to include both relatively fertile and infertile soils (Fig. 1). Transects were divided into two adjacent strips representing manure and no manure treatments. Each treatment (manure and no manure strips) contained eleven 12 m × 12 m plots (16 rows at 0.76-m spacing). Plots were numbered from one to eleven in each strip, with plot number six positioned in the lowest yielding area according to the yield map.

Fresh solid beef feedlot manure was applied in early spring of 1997 at a rate of 112 Mg ha^{-1} wet or 69.6 Mg ha^{-1} dry. This rate was chosen based on manure supplying the recommended 224 kg N ha^{-1} crop requirement. All ammonium N was assumed to be lost since the manure could not be incorporated (ridge-tillage). A 20% N availability from organic N was assumed for the first year. Consequently, applying manure to meet the crop N requirement led to an over-application of P and K. Four samples of the manure were collected during the application for nu-

Corn Yield - 1996   Bare Soil - 1994
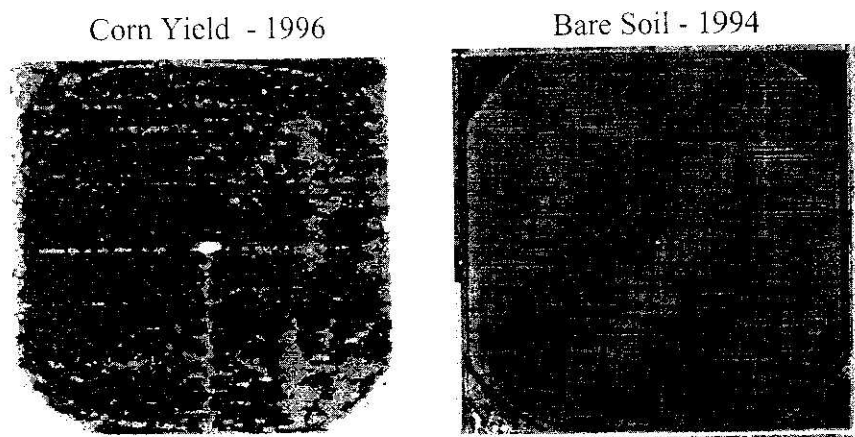
Figure 1. Yield map for irrigated corn in 1996 and bare soil image showing location of research plots.

trient analysis. The manure was incorporated 2 weeks after application with roto-tilling that was part of the planting operation.

Starter fertilizer was applied as 10-34-0 (ammonium polyphosphate) in 1997 at the rate of 78.6 kg ha^{-1} in furrow with the seed. In 1998, 10-34-0 was applied at 235.8 kg ha^{-1} using a one-pass injection system before planting. In both years, the field was planted the last week of April at ~85,000 seeds ha^{-1} to NC + hybrid 4880. This 112 day hybrid required 2430 growing degree days for maturity and was well adapted to ridge-till systems, early spring planting, and continuous corn systems. The grower made all tillage operations and management decisions.

Chlorophyll meter readings (Minolta SPAD 502) were taken biweekly from the V10 to R3 growth stages. Meter readings were based on a 30-plant average and collected from the middle ten rows within each plot. Readings were taken on the upper most collared leaf prior to anthesis and on the ear leaf after anthesis (Peterson et al., 1993). Leaf tissue samples were collected at the V12, R1, and R3 growth stages. The V12 sampling consisted of 80 circular disks (1.0-cm diameter) taken from the upper most collared leaf. The R1 sampling consisted of 80 circular disks taken from the ear leaf. The R3 sampling consisted of 20 ear leaves less the midrib.

No manure was applied to any plots for the 1998 growing season. However, all plots received a uniform sidedress application of 177 kg N ha^{-1} as anhydrous ammonia in the spring. Chlorophyll meter readings were taken on a biweekly basis beginning at V10 and ending at R3 growth stage. The readings represented a 30-plant average taken on the upper most collared leaf prior to anthesis and ear

leaf after anthesis. Leaf tissue samples (20 leaves, less the midrib) were collected at the V12 (upper most collared leaf) and R1 (ear leaf) growth stages. In both years the leaf tissue samples were analyzed for N, P, K, Ca, Mg, S, Zn, B, Mn, Cu, Fe, Na, and Al using the ICP emission spectroscopy method described by Hunge and Schulte (1985).

Grain weight was determined from the middle 8 rows (12-m length) of each plot in both 1997 and 1998 using a 3-row plot combine. Final yield was corrected to 155 g kg^{-1} (15.5%) moisture.

Soil samples were taken from within the row in the spring of 1998. Twelve cores per plot were obtained in depth increments of 0–7.5, 7.5–15, and 15–30 cm. Two high yielding and two low yielding no-manure and the adjacent manure plots were sampled. Soils were analyzed for pH, organic matter, nitrate-N, P, K, Mg, Ca, S, Zn, Mn, Cu, Fe, and B using methods described by Missouri Agricultural Experiment Station SB 1001 (1998).

Chlorophyll meter data were analyzed using the sufficiency index concept (Peterson et al., 1993). Relative values, coefficients of variation, and the MIXED procedure of SAS (Littell et al., 1996) were used to analyze leaf nutrient concentrations, soil, and yield data. Leaf nutrient concentrations were compared to critical nutrient ranges (CNR) for Nebraska. Early season analyses were compared to CNRs for silking stage. The CNRs were defined as: 1) deficient – 80% or less yield, deficiency symptoms present, 2) low – 80 to 95% yield, hidden hunger area, 3) sufficient – 95 to 100% yield, normal yield, and 4) high – 100 to 70% yield, abnormally high or excessive resulting in possible yield reduction caused by plant toxicity.

RESULTS AND DISCUSSION

Manure analysis showed that Na and soluble salts additions were acceptable (<500 and 5000 kg/ha, respectively) according to University of Nebraska guidelines. Manure pH was lower than expected considering most beef rations are high in calcium carbonate (Table 1). About two-thirds of the N in the manure was in the organic form. First-year N availability from fresh beef feedlot manure would typically be adjusted to ~35%. Utilization of ammonium-N would vary depending on cultural practices. Release of S and P from manure is expected to coincide with N mineralization.

Chlorophyll meter readings from the manure strips in 1997 were greater (P<0.05) at the V10, VT, R1 and R3 growth stages than for the no-manure strips. However, plots within a treatment (manure or no-manure strip) were only different at VT and R3 growth stages. Examination of plot data from individual replications revealed that each replication responded differently to the manure application in terms of which plots were responsive. Differences in fertility status generally re-

Table 1. Average Chemical Analysis of Fresh Beef Feedlot Manure Applied to Plots in 1997, Shelton, NE

Analysis	Concentration (Dry Basis)	Amount of Element Added (kg ha^{-1})
Organic nitrogen, mg N g^{-1}	16.7	1162
Ammonium-N, mg N g^{-1}	6.1	426
Nitrate-N, mg N kg^{-1}	2.8	<1
Total nitrogen, mg N g^{-1}	22.9	1588
Phosphorus, mg P g^{-1}	7.5	522
Potassium, mg K g^{-1}	20.0	1391
Sulfur, mg S g^{-1}	4.6	320
Calcium, mg Ca g^{-1}	21.2	1475
Magnesium, mg Mg g^{-1}	6.5	452
Sodium, mg Na g^{-1}	3.7	257
Zinc, mg Zn kg^{-1}	137	10
Iron, mg Fe kg^{-1}	9070	631
Manganese, mg Mn kg^{-1}	220	15
Copper, mg Cu kg^{-1}	25	2
Electrical conductivity, mmho/cm (1:5 dry wt.)	38.1	
pH (1:5 on dry wt. basis using distilled water)	6.9	
Moisture, %	37.9	
Solids, %	62.1	

sulted in the most fertile areas being at the end of each strip as intended. However, the trend in fertility status within the strip was different for each replication. This made it impractical to compare crop responses for any given position (plot number in the sequence) along the strip. For this reason, side-by-side comparisons (i.e., manure and no manure plots) were used to temporally summarize crop responses. Within the manure strips, plots at the end of each replication were used as a reference and all other values were normalized to the reference plot for that replication unless otherwise specified.

In 1997, chlorophyll meter readings indicated 64% of the no-manure plots were apparently N deficient (< 95% sufficiency index) at V10. By VT, 80% of the no-manure plots were identified as stressed. The percentage of no-manure plots that were N deficient remained at 80% through R3 before increasing slightly to 82% by R4. No-manure strips for three of the five replications had average sufficiency index values < 95% by V10 and four of the five were < 95% by VT. Only one replication managed to stay above the 95% sufficiency index throughout the growing season, although several plots within this replication developed a de-

ficiency. Replications with the lowest average sufficiency index values had the greatest yield differences between the manure and no-manure plots.

In 1998, 45% of the no-manure plots were identified as being N deficient by V12 according to chlorophyll meter criteria. However, that number of N deficient plots declined to 7% by R1 and 2% by R3. Only one replication had an average sufficiency index value < 95% by V12. By the R1 growth stage, no replications had an average sufficiency index that would indicate a N deficiency. Unlike 1997, visual deficiency symptoms were not observable in 1998. Nitrogen deficiency was not expected in 1998 since all plots received a sidedress application of 177 kg N ha^{-1} as anhydrous ammonia. These data support the observation that chlorophyll meter readings provide a good indication of apparent crop N status as well as yield potential (Schepers et al., 1998).

In 1997, increases in leaf N, P, S, Mg, and Zn concentrations were found in the manure plots (Table 2), while concentrations for other nutrients were not different. Leaf concentrations of N and P at silking showed the greatest response to manure application. Regression analysis (r^2) between nutrient concentration and yield were 0.65 for N and 0.64 for P in 1997 (Fig. 2). Higher leaf N and P concentrations for the manure plots at the R1 growth stage versus yield most clearly illustrated the relationship with higher yields. Nitrogen was presumed to be a yield-limiting factor in 1997 because no N fertilizer was applied to the no-manure plots. Leaf N concentrations for three sampling dates were 25 (VT), 26 (R1), and 26 mg g^{-1} (R3) for no-manure plots, which corresponded to the low CNR (22–27 mg g^{-1}). Leaf N concentrations in the manure plots were 30 (VT), 33 (R1), and 31 mg g^{-1} (R3), which were in the sufficient CNR (27–35 mg g^{-1}). Plots with SPAD readings below 54 at the R1 growth stage in 1997 (i.e., <95% sufficiency index) would be expected to respond to additional N (Figure 3). As such, even some of the plots receiving manure were probably N deficient.

Leaf P concentrations were 2.0 (VT), 2.0 (R1), and 1.9 mg g^{-1} (R3) for the check plots, which corresponded to the low CNR (2.0–2.4 mg g^{-1}). Leaf P in the manure plots were 2.5 (VT), 2.7 (R1), and 2.3 mg g^{-1} (R3), which were in the sufficient CNR (25–4.0 mg g^{-1}). Plant analysis indicated that leaf K concentrations were in the low CNR (12–19 mg g^{-1}) for all plots. However, regression analysis indicated leaf K concentration was not limiting yield. Furthermore, soil analyses (data not shown) indicated high levels of K and the addition of manure did not increase leaf K concentrations (Table 2).

Manure applied in 1997 had a carry-over effect (P<0.01) on yield response in 1998 (12.8 Mg ha^{-1}) compared to plots that received no manure or fertilizer in 1997 (11.9 Mg ha^{-1}). In comparison, 1997 yields for the no-manure and manure treatments were 10.2 and 12.2 Mg ha^{-1} (P<0.01). In 1998, the residual effect of the 1997 manure application was observed for leaf P, Mg, and Zn concentrations (Table 2). Leaf nutrient concentrations at silking showed P had the greatest difference in response to manure application. The higher leaf P concentration for the

Table 2. Chemical Concentrations in Corn Leaf Tissue Collected for Two Years at the R1 Growth Stage in Response to Manure Application (No Fertilizer N) in 1997 and Uniform Fertilizer Application in 1998

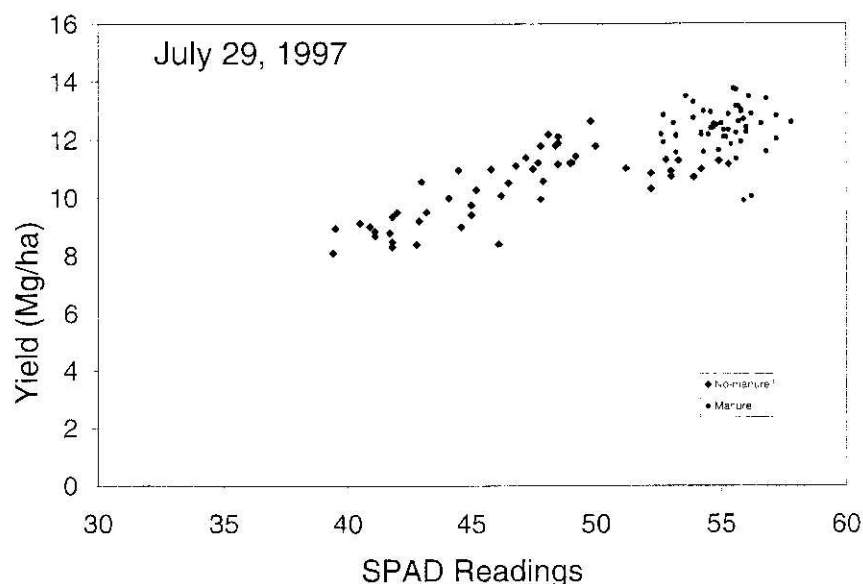| Element	1997			1998		
	No-Manure	Manure	Sign.*	No-Manure	Manure	Sign.
Nitrogen, mg N g^{-1}	26.1	32.6	**	32.5	32.5	n.s.
Potassium, mg K g^{-1}	16.7	17.9	n.s.	18.3	18.5	n.s.
Phosphorus, mg P g^{-1}	2.05	2.68	**	3.09	3.54	***
Sulfur, mg S g^{-1}	1.68	1.87	*	2.16	2.07	n.s.
Magnesium, mg Mg g^{-1}	1.43	1.50	*	1.40	1.53	**
Zinc, mg Zn kg^{-1}	27.2	35.5	***	23.1	19.5	**

*, **, *** Significant at P ≤0.05, 0.01, and 0.001 level, respectively.
n.s. signifies non-significant.
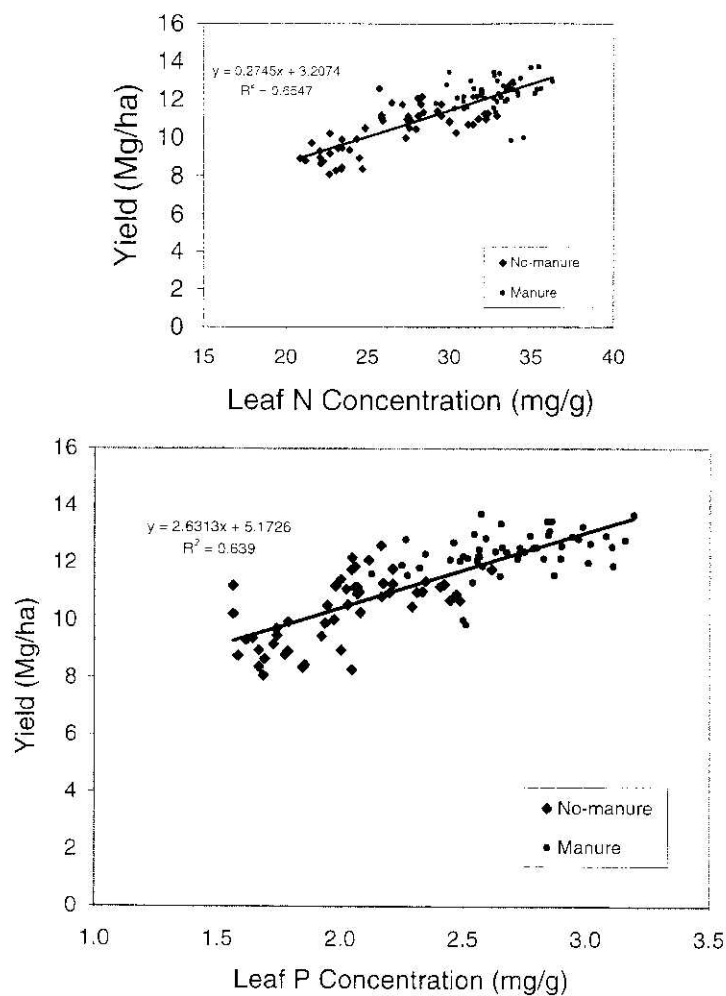
Figure 2. Relationship between leaf N and P concentration at the R1 growth stage on corn yield during the year of manure application to spatially variable plots.

no-manure plots in 1998 (3.1 mg g⁻¹) than in 1997 (2.1 mg g⁻¹) is attributed to a three-fold increase in starter fertilizer rate in 1998. Even though P concentrations in 1998 were lower in the no-manure plots (3.1 mg g⁻¹) than the manure plots (3.5 mg g⁻¹), all were still considered sufficient (CNR of 2.5–4.0 mg g⁻¹). Leaf N and S concentrations at silking were not affected by the previous manure application. This suggests the uniform N fertilizer application in 1998 was adequate

16 ┤
14 ┤   July 29, 1997
12 ┤
Yield (Mg/ha)
10 ┤
8 ┤
6 ┤
4 ┤
2 ┤
0 ┤
    30   35   40   45   50   55   60
            SPAD Readings

Figure 3.   Relationship between chlorophyll meter readings at the R1 growth stage and corn yield in the year of manure application.

for the check plots. Leaf Zn concentration was significantly lower for the manure plots in 1998 (19.5 mg kg⁻¹) compared to the no-manure plots (23.1 mg kg^{-1}). No explanation is offered other than that a P : Zn interaction could have developed in the soil because of the manure application in 1997 and the extra starter fertilizer applied in 1998. This possibility goes along with the observation by Meek et al. (1979) who found the use of manure not only provides P for plant growth but also enhances the availability of fertilizer P.

Historical soil data from intensive grid sampling in 1994 (not shown) indicated relatively fertile areas were higher in organic matter, nitrate-N, and Bray-P levels than relatively infertile areas. Soil pH was quite consistent between fertile and infertile areas, perhaps because the irrigation water contains Ca and Mg sulfates and carbonates. Fertilizer N was required for irrigated corn production in all field areas to meet yield goals. Phosphorus levels were considered low, whereas all other nutrients were considered adequate.

Soil samples collected in 1998 indicated considerable stratification within the surface 15 cm. Mean soil test values were generally higher after manure application and especially in the upper 7.5-cm soil depth.

Yield variation within transects (CVs) revealed less spatial variability than anticipated. In both years, the CVs were less than ten percent. Neither plot posi-
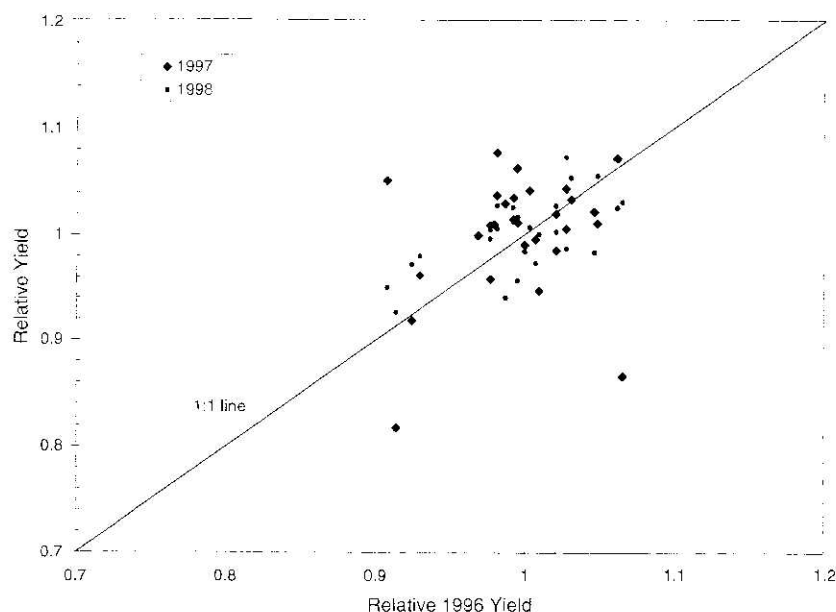
Figure 4. Relative yield of corn for plots in prior to manure application (1996) compared to relative yields for the year of manure application (1997) and the following year with only fertilizer application (1998).

tion along the transect nor position by treatment interaction were significant either year. This suggests that the response to manure was essentially equal at all transect positions. However, graphical presentation of yield along each transect (not shown) revealed that yield response to manure had a different spatial pattern for each replication. Combining data from the five spatially different replications resulted in no position or position by treatment effects.

As expected, manure increased yields in both years. In 1997, the manure lead to a 21% yield increase over the no-manure plots and a 10% yield increase above the field average of 11.3 Mg ha^{-1}. The large yield increase observed in 1997 was attributed to the lack of fertilizer application to the no-manure plots other than a nominal application of starter fertilizer ($\sim$8 kg N ha^{-1} and 12 kg P ha^{-1}). Chlorophyll meter readings at R1 (29 July, 1997) also showed considerable variability in chlorophyll status compared to the manure plots. Since many nutrient deficiencies affect plant chlorophyll status, it is not appropriate to attribute the reduced chlorophyll meter readings solely to an N deficiency.

In 1998, the manure treatment resulted in a 7% yield increase over the no-manure plots and a 3% increase above the field average. The yield increase ob-

served in 1998 was attributed to P supplied by the manure. The higher yields in no-manure plots observed in 1998 compared to 1997 were influenced by the application of anhydrous ammonia, three-fold increase in starter fertilizer rate, and good growing season conditions. Seasonal precipitation in 1997 was 33.3 cm and in 1998 was 40.6 cm, compared to the 30-year average of 41.2 cm. May and June precipitation in 1997 was near ideal with 10.4 cm, but in 1998 it was excessive with 24.4 cm. Growing degree days for May through September (10-degree C minimum and 30-degree C maximum) for the two years were 2799 and 3078, respectively.

Manure application suppressed yields in some spots during that first year, but reduced the spatial variability in yield the second year. McCalla (1974) cited several studies where high rates of manure applications lead to reduced yields the first year after application. Larney and Janzen (1997) reported a yield reduction the first year following manure application on non-eroded soils. Unfortunately, measurements were not taken to monitor changes in soil physical properties associated with manure application. Producers avoid spring manure applications because of potential compaction problems.

Comparison of yields for specific plots where yield map data were available in 1996 shows that the variability in relative yield was reduced by manure application (Figure 4). The standard deviation for relative yield in 1996 was 0.043 compared to 0.058 for 1997 and 0.039 for 1998. Not all of this reduction in spatial variability in yield in 1998 can be attributed to the manure treatment because of the extra starter fertilizer applied by the producer.

CONCLUSIONS

This study showed that there was a multiple year benefit from manure application. The manure application led to greater yields and improved the productivity of marginal or relatively infertile soils as well as relatively fertile soils. Nitrogen and P were shown to be limiting factors during the first year of the study. Neither N nor P was limiting the second year, but yield data suggest there was a carry-over benefit of manure application. The use of site-specific management practices to identify areas of relatively infertile soils and a corresponding manure application can reduce spatial variability. This study demonstrates the value of on-farm research by revealing spatial aspects that would be difficult to appreciate in plot studies with adjacent replications. It also identifies the need to develop such studies in consultation with producers. In this study, the producer modified the starter fertilizer program for the whole field in the second year based on the first year results. Ideally, the starter fertilizer programs would have been the same both years.

REFERENCES

Bates, T.E. 1971. Factors affecting critical nutrient concentrations in plants and their evaluation: a review. Soil Sci. 112:116–130.

Carr, P.M., G.R. Carlson, J.S. Jacobsen, G.A. Nielsen, and E.O. Skogley. 1991. Farming soils, not fields: A strategy for increasing fertilizer profitability. J. Prod. Agric. 4:57–61.

Hornick, S.B. 1982. Organic wastes for revegetating marginal lands. Biocycle. 23:42–43.

Hunge, Chao-Wong Luh and E.E. Schulte. 1985. Digestion of plant tissue for analysis by ICP emission spectroscopy. Commun. Soil Sci. Plant Anal. 16:943–958.

Larney, F.J., and H.H. Janzen. 1997. A stimulated erosion approach to assess rates of cattle manure and phosphorus fertilizer for restoring productivity to eroded soils. Agric. Ecosys. Environ. 65:113–126.

Littell, R.D., G.A. Milliken, W.W. Stroup, and R.D. Wolfinger. 1996. SAS system for mixed models. SAS Insst., Cary, NC.

McCalla, T.M. 1974. Use of animal wastes as a soil amendment. J. Soil Water Cons. 29:213–216.

Meek, B.D., L.E. Graham, T.J. Donovan, K.S. Mayberry. 1979. Phosphorus availability in a calcareous soil after high loading rates of animal manure. Soil Sci. Soc. Am. J. 43:741–744.

Missouri Agricultural Experiment Station SB 1001. 1998. Recommended chemical soil test procedures for the North Central Region. North Central Regional Research Publication No. 221 (Revised).

Peterson, T.A., T.M. Blackmer, D.D. Francis, and J.S. Schepers. 1993. Using a chlorophyll meter to improve N management. NebGuide G93-1171-A. Cooperative Extension Service. University of Nebraska, Lincoln.

Schepers, J.S., T.M. Blackmer, and D.D. Francis. 1998. Chlorophyll meter method for estimating nitrogen content in plant tissue. In: Y.P. Kalra (ed.) Handbook of References Methods for Plant Analysis. CRC Press, Boca Raton, FL. pp. 129–135.

Sharpley, A.N., and S.J. Smith. 1995. Nitrogen and phosphorus forms in soils receiving manure. Soil Sci. 159:253–258.

Sommerfeldt, T.G., and C. Chang. 1985. Changes in soil properties under annual applications of feedlot manure and different tillage practices. Soil Sci. Soc. Am. J. 49:983–987.

Sommerfeldt, T.G., C. Chang, and T. Entz. 1988. Long-term annual manure applications increase soil organic matter and nitrogen, and decrease carbon to nitrogen ratio. Soil Sci. Soc. Am. J. 52:1668–1672.

Sweeten, J.M., and A.C. Mathers. 1985. Improving soils with livestock manure. J. Soil Water Conserv. 40:206–210.

Tiarks, A.E., A.P. Mazurak, and L. Chesnin. 1974. Physical and chemical properties of soil associated with heavy applications of manure from cattle feedlots. Soil Sci. Soc. Am. Proc. 38:826–830.

Wood, C.W., D.W. Reeves, R.R. Duffield, and K.L. Edmisten. 1992. Field chlorphyll measurements for evaluation of corn nitrogen status. J. Plant Nutr. 15:487–500.